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Scattering of Acoustic Waves from Ocean Boundaries

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LONG-TERM GOALS

Development of a physical model of high-frequency acoustic interaction with the ocean floor, including penetration through and reflection from smooth and rough water/sediment interfaces, scattering from the interface roughness and volume heterogeneities and propagation within the sediment. The model will aid in the detection and classification of buried mines and improve SONAR performance in shallow water.

OBJECTIVES

1) Determination of the correct physical model of acoustic propagation through ocean sediments and scattering from sediment interfaces through the analysis of in situ measurements.
2) Development of predictive models that can account for the all of the physical processes and variability of acoustic propagation and scattering in ocean environments with special emphasis on propagation in shallow water waveguides and scattering from ocean sediments.
3) Development of the new experimental techniques to measure geo-acoustic parameters in the ocean.

APPROACH

1) *Analysis of Scattering Cross Section from Rough Fluid and Elastic Ocean Sediments*: Finite elements (FE) provides a noiseless testbed for the validation of approximate models. In this case, perturbation theory and the Kirchhoff approximation were compared with an FE scattering model to ascertain the range of validity. The FE model can also be compared with navy standard models such as the GeoAcoustic Bottom Interaction Model (GABIM) which is based on perturbation theory to determine their range of validity. [Jackson, 2010.]
2) *Longitudinally and axi-symmetric propagation modeling for range dependent environments*: Finite element propagation models are be extended into three dimensions either by taking a consine transform for the out-of-plane wave number resulting in longitudinally invariant geometry or by considering a solution which is axi-symmetric. Both of these solutions were considered for two 3D geometries and compared with other models. A wedge geometry was calculated for both the axi-symmetric and longitudinally invariant case and compared with a

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parabolic equation solution. Propagation over a cosine hill was computed and compared with coupled modes.

3) *Investigation into Interface Wave Dispersion in Layered Media:* One of the most interesting results from the FE scattering work was the identification of roughness induced interface waves. This idea was extended to consider the dispersion of interface waves for comparison with a field experiment. [Potty, 2012]. In this case, the wave speeds were determined using a wave number decomposition scheme on the interface.

4) *Bottom loss data collection at TREX13:* Bottom loss data from 5 – 30 kHz were collected as part of the Target and Reverberation Experiment 2013 (TREX13). Specifically, an acoustic system mounted on the ARL ROV was used to collect data over the "transition regions" along the main reverberation path. These data are still in the process of being analyzed.

WORK COMPLETED

Analysis of Scattering Cross Section from Rough Fluid and Elastic Ocean Sediments:
A finite element model was developed for scattering from both fluid and elastic sediments. The model consists of a tapered plane wave incident on either flat or rough interfaces. An example of scattering is shown in Figure 1. In the figure, the reflection from a flat fluid/elastic interface is compared with scattering from a rough fluid/elastic interface. In the flat case, the incident and reflected waves are evident in the top (fluid) layer. In the lower (elastic) layer, the shear wave is evident. At this angle, the compressional wave is evanescent. In the bottom panel, the rough interface induces a compressional wave, evident at the 20 m mark. Also, notable is the strong induced interface wave.

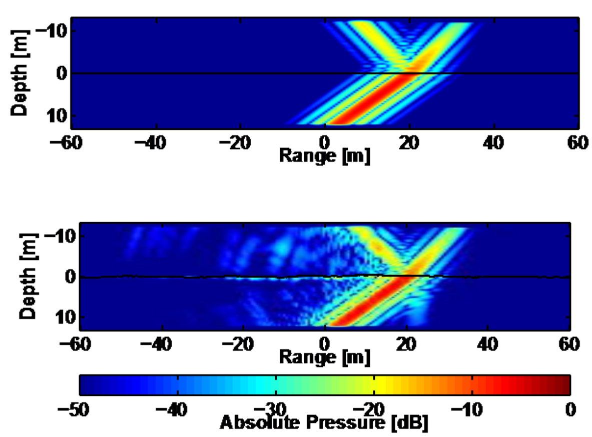

Figure 1: The magnitude of pressure for a tapered plane wave scattering from an elastic interface. In the top panel, the interface is flat. In the bottom panel, the interface is rough. The grazing angle is 45 degrees.

Longitudinally and axi-symmetric propagation modeling for range dependent environments:
The finite element propagation model was extended to domains with strong range dependence. In these models, the pressure was computed in three dimensions by taking a cosine transform along one dimension resulting in longitudinal invariance. An example of a range dependent model is the canonical wedge shown in Figure 2. The pressure field was calculated with finite elements and

compared with a parabolic solution and an axi-symmetric FE model. Axi-symmetric models are desirable due to the low computational load. It was found that in certain geometries, the axi-symmetric model performed as well as the longitudinally invariant model. Agreement with the parabolic equation method was excellent.

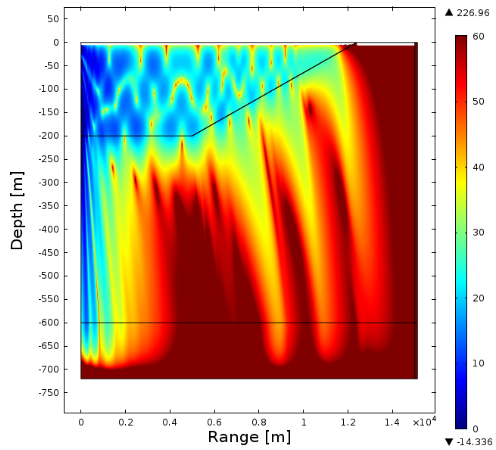

Figure 2: The magnitude of the pressure field of propagation in a wedge environment.

Investigation into Interface Wave Dispersion in Layered Media:
It was found through the scattering analysis that finite element models are an excellent method for the exploration of interface waves. An experiment conducted by Potty and Miller in Narragansett Bay, Rhode Island displayed considerable dispersion of interface waves due to the sediment layering structure.[Potty, 2012] The experiment was modeled in finite elements. An example of the real part of pressure field for the computational domain is shown in Figure 3. Note the strong interface wave near the source. The phase speed of the interface wave was determined by taking a spatial Fourier transform along the interface. The model was calculated for frequencies between 1 and 20 Hz and compared with experimental data.

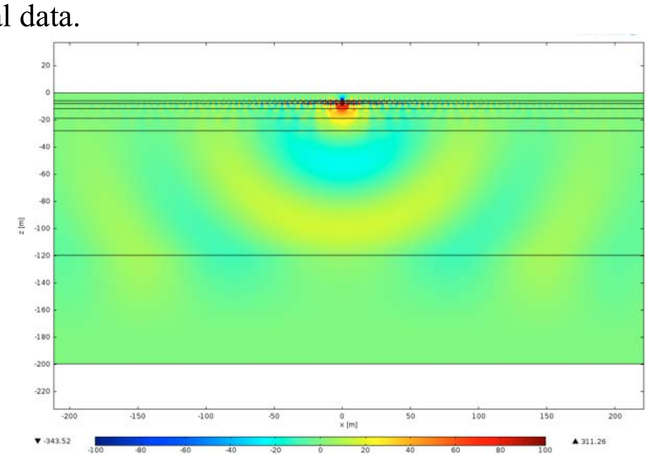

Figure 3: The real part of the pressure field calculated for a layered interface as described in Potty, 2012.

Bottom loss data collection at TREX13:
Bottom loss data from 5-30 kHz were collected along the main reverberation path as shown in the left panel of Figure 4. The colored circles correspond to some of the bottom loss data collected. These data were collected by towing the ROV mounted acoustic system along the path. The path was characterized by a series of "transition regions". These are evident in the figure as lighter and darker stripes across the path. Along with data taken along the path, each transition region was further investigated by a series of measurements taken close to the ocean bottom. These data were taken concurrently with interface roughness measurements from the ARLUT AUV mounted laser profiling system. An example of a transition region investigation is shown in the right panel of Figure 4. The colored circles indicate a data collection point.

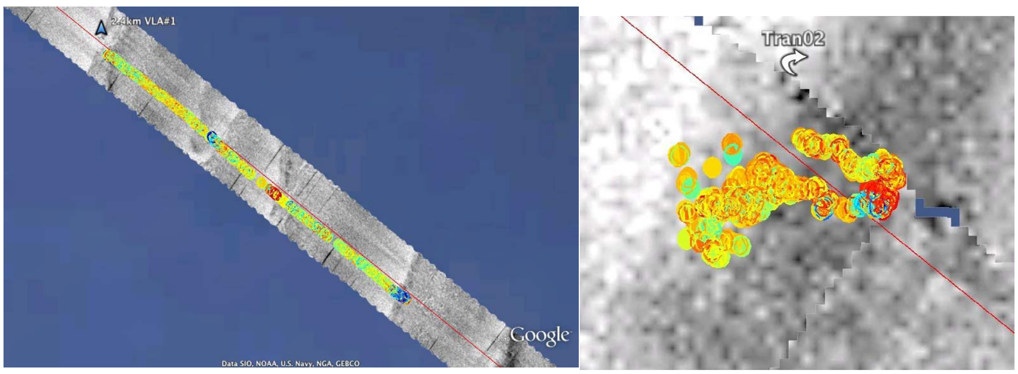

Figure 4: Location of portions of the bottom loss data taken at TREX13 by ARL:UT.

RESULTS

Analysis of Scattering Cross Section from Rough Fluid and Elastic Ocean Sediments:
The scattering cross section and angle dependent bottom loss was computed for the finite element scattering model and compared with several other models. Shown in Figure 5 are the results of the comparison. For the fluid model, it was found that the finite element model compared well with both perturbation theory and the Kirchhoff approximation. There were small deviations for the Kirchhoff approximation at small grazing angles due to shadowing effects.

The case of scattering from an elastic sediment is shown in the right panel of Figure 5. Note that perturbation theory was calculated for a sediment with and without a shear wave. It was found that the Kirchhoff approximation was inaccurate at shallow angles, since it was too sensitive to the intromission angle of the shear wave. Perturbation theory over estimated the role of scattering at the critical angle when shear was included and underestimated the effect when shear was neglected.

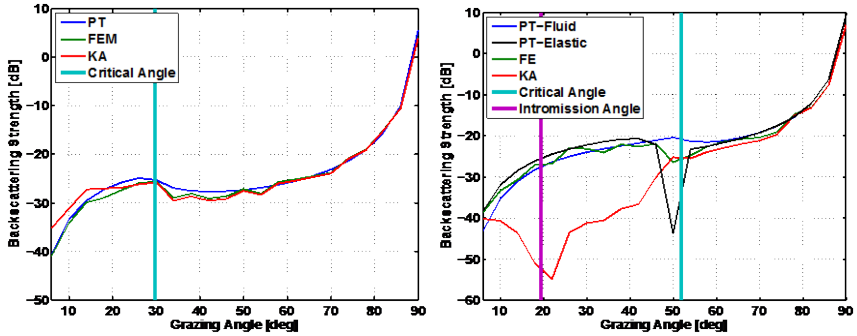

Figure 5: The backscattering strength for a fluid bottom (left) and an elastic bottom (right). Shown are the results from perturbation theory (black), perturbation theory neglecting the shear wave component (blue), finite elements (green) and the Kirchhoff approximation (red). Also shown is the critical angle for the compressional wave and the intromission angle for the shear wave.

Longitudinally and axi-symmetric propagation modeling for range dependent environments:
In addition to the wedge environment, the longitudinally invariant finite element model was computed for propagation over a cosine hill for comparison with coupled modes. The environment is described in [Ballard, 2013]. In this case, the axi-symmetric model was found to agree well for propagation directly over the hill. However, propagation along the hill required the LI formulation. The finite element model agreed well with the coupled mode models as shown in Figure 6.

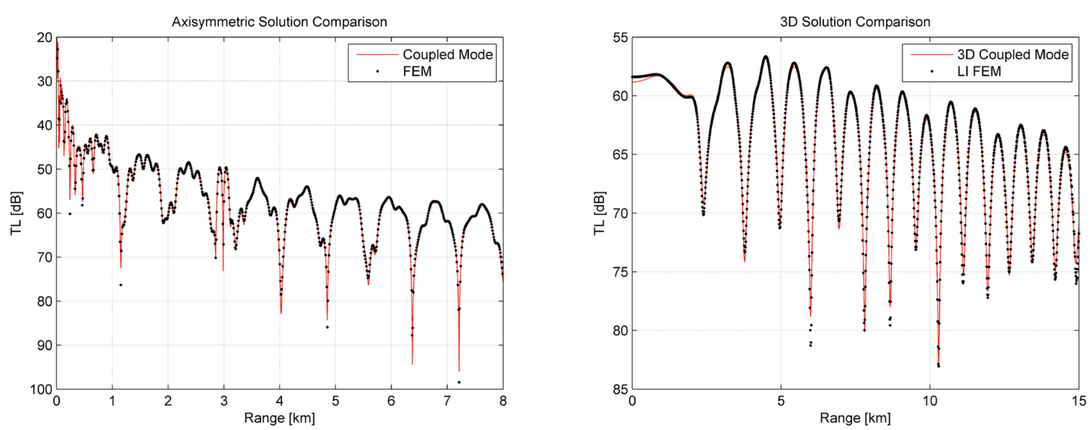

Figure 6: Transmission loss for propagation over a cosine hill (left) and along the hill (right).

Investigation into Interface Wave Dispersion in Layered Media:
Results from the models of interface wave dispersion were compared with data as shown in Figure 7. It was found that in general the finite element model agreed with the data and the dynamic stiffness matric approach. Data that do not agree with the models may have been produced by range dependent layering structure. Finite element models are well suited to investigate this hypothesis.

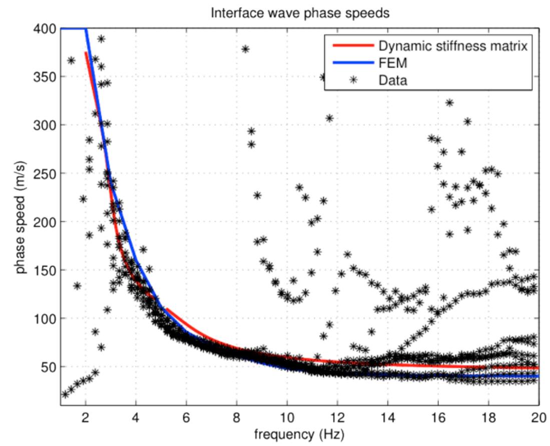

Figure 7: A comparison of the finite element model predictions of interface wave dispersion (blue) with the dynamic stiffness matrix (red) and data (black aterisks).

Bottom loss and surface roughness data collection at TREX13:
Figure 8 shows an example of bottom loss data from along the track (left) and over a transition (right). In the figure, the direct path is evident as the straight red trace at short ranges. The varying red trace is the bottom reflection. It varies as the depth of the ROV. Variations in the intensity of the return is proportional to the normal incident bottom loss. This work is ongoing.

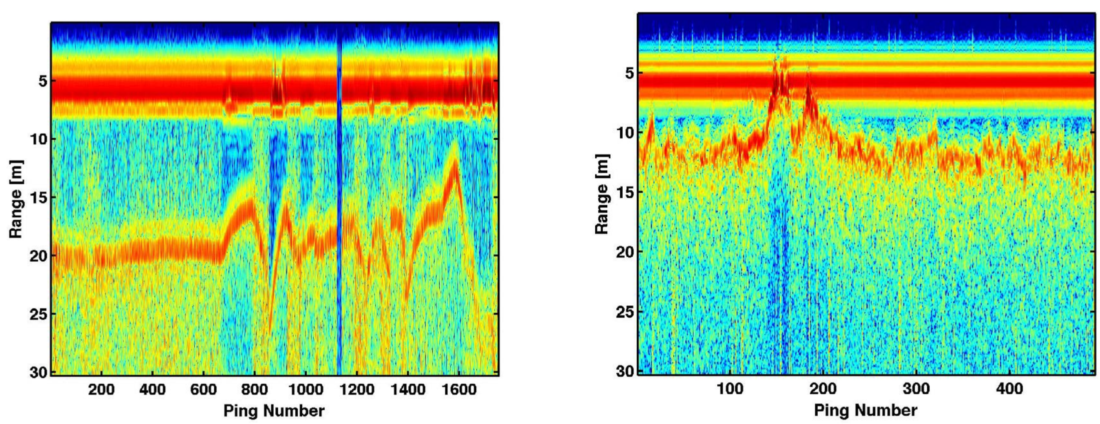

Figure 8: Examples of the bottom loss data taken along the reverberation track (left) and over transition region 2.

IMPACT/APPLICATIONS

The finite element reflection loss models could transition into a new high frequency and low frequency reflection loss (LFBL/HFBL) data curves for NAVO based on site specific characteristics. The 3D LI model can be used to understand propagation and reverberation in complex environments. An understanding of normal incident reflection loss is critical to sediment characterization and mine burial prediction. The TREX13 measurements will serve as ground truth bottom loss and interface roughness measurements for reverberation modeling.

RELATED PROJECTS

Under the iPUMA and SSAM Sediment Environmental Estimation (iSSEE) program, this group is also developing sediment characterization algorithms for AUV sonars based on the measurements and models previously developed by this program. Additionally, the models developed in this research will be used to increase the fidelity of sonar trainers under the High Fidelity Active Sonar Trainer (HiFAST) program. There will be significant collaboration with Dr. Nicholas Chotiros, particularly for theoretical development of bulk acoustic/sediment modeling and laser roughness measurements.

REFERENCES

Jackson, D. Odom, R. Boyd, M. and A. Ivakin. A GeoAcoustic Bottom Interaction Model (GABIM). IEEE J. Ocean Eng., 35(3) : 603–617, 2010.

G. Potty and J. Miller. Measurement and modeling of Scholte wave dispersion in coastal waters. In Proc. of Third Int. Conf. on Ocean Acoustics, Beijing, China, 21-25 May 2012.

M. Ballard, B. Goldsberry, and M. Isakson. A three-dimensional propagation model with stepwise coupled modes. J. Acoust. Soc. Am., Submitted, 2013.

PUBLICATIONS

1. M. Isakson, and N. Chotiros. Finite Element Modeling of Acoustic Scattering from Fluid and Elastic Interfaces, IEEE J. Ocean Eng., Submitted.
2. M. Ballard, B. Goldsberry, and M. Isakson. A three-dimensional propagation model with stepwise coupled modes. J. Acoust. Soc. Am., Submitted, 2013.
3. M. Isakson, N. Chotiros, R. Abraham Yarbrough, and J. Piper. Quantifying the effects of roughness scattering on reflection loss measurements. J. Acoust. Soc. Am., J. Acoust. Soc. Am. Volume 132, Issue 6, pp. 3687-3697 (2012).
4. B. Goldsberry and M. Isakson. Modeling scattering rough poroelastic surfaces using comsol multiphysics. In Proc. 2013 COMSOL Conference in Boston. COMSOL, October 2013.
5. A. L. Bonomo, M. Isakson, and N. Chotiros. Modeling scattering rough poroelastic surfaces using comsol multiphysics. In Proc. 2013 COMSOL Conference in Boston. COMSOL, October 2013.
6. M. Isakson and N. Chotiros. A finite element model for backscattering from fluid and elastic ocean sediments. In 1st International Conference and Exhibition on Underwater Acoustics, 2013.
7. N. Chotiros and M. Isakson. An efficient poro-elastic model for characterizing a range of sediments. In 1st International Conference and Exhibition on Underwater Acoustics, 2013.

PRESENTATIONS

M. Isakson and N. Chotiros. Rough interface acoustic scattering from layered sediments using finite elements, J. Acoust. Soc. Am. Volume 133, Issue 5, pp. 3304-3304 (2013).

A. Bonomo, M. Isakson and N. Chotiros. A study of the reflection coefficients and backscattering effects of one-dimensional rough poroelastic surfaces using the finite element method, J. Acoust. Soc. Am. Volume 133, Issue 5, pp. 3303-3303 (2013).

B. Tran, S. Joshi and M. Isakson, Applicability of two-dimensional boundary scattering models as a proxy for three-dimensional models, J. Acoust. Soc. Am. Volume 133, Issue 5, pp. 3529-3529 (2013).

N. Chotiros, and M. Isakson, High frequency backscattering from sandy sediments: single or multiple scattering, J. Acoust. Soc. Am. Volume 133, Issue 5, pp. 3303-3303 (2013).

B.M. Goldsberry and M.J. Isakson, Comparison of two-dimensional axial-symmetric and two-in-one-half dimensional Green's function methods for three-dimensional shallow water acoustic propagation using finite element methods, J. Acoust. Soc. Am. Volume 133, Issue 5, pp. 3529-3529 (2013).

B. Tran, S. Joshi and M. Isakson. Validity of first-order perturbation theory for scattering from one-dimensional and two-dimensional rough surfaces described by power-law spectra, J. Acoust. Soc. Am. Volume 132, Issue 3, pp. 2093-2093 (2012).

M. Isakson. An introduction to the Underwater Acoustics Technical Committee, J. Acoust. Soc. Am. Volume 132, Issue 3, pp. 1900-1900 (2012).

M. Isakson and N. Chotiros. Modeling the effect of interface roughness on bottom loss from layered interfaces with finite elements, J. Acoust. Soc. Am. Volume 132, Issue 3, pp. 1944-1944 (2012).

N. Chotiros and M. Isakson. A broadband model for a range of ocean sediments, J. Acoust. Soc. Am. Volume 132, Issue 3, pp. 2092-2092 (2012).